INDUCTION HEAT TREATMENT METHOD AND ARTICLE TREATED THEREBY

FIELD OF THE INVENTION

[0001] The present invention relates to a method of induction heat treatment. More specifically, the invention comprises a method for induction hardening certain metal components, particularly those having a shape that prevents uniform induction coupling over the entire surface to be hardened in a single step. Most particularly, the invention comprises a method for induction hardening the outer surfaces of the trunnions of a spider of a steel tripod-type constant velocity joint.

BACKGROUND OF THE INVENTION

[0002] The tripod-type constant velocity joint is widely used in automotive vehicles. It is most frequently used to provide a plunging and angulating constant velocity joint for use with halfshafts, the name given to the two driveshafts or axle shafts that run from the transaxle to the wheels in front wheel drive vehicles. A plunging joint is one that permits axial movement between the shafts. Because it is widely used in automotive vehicles, the tripod joint is manufactured in relatively high volumes. A tripod joint consists of a spider which comprises a hub, often with a splined bore in its center, and three angularly-spaced shafts or trunnions extending from the hub, and three roller bearings. Each roller bearing is fixed on an end of a trunnion and is adapted to slide in a corresponding groove that is cut into the inside surface of a tube-like housing. The power to the driven wheels of a vehicle is transmitted through the trunnions and the point of contact between the three bearings and three grooves. Given the

magnitude and cyclic nature of the loading of the trunnions, they have carefully defined requirements for strength, toughness and fatigue resistance.

[0003] While variations exist in the designs for and materials used in spiders of different manufacturers, a spider is typically formed by forging from a pearlitic/ferritic steel blank, and is then subjected to various metal forming, finishing and heat treatment steps to produce a finished article. In one example, the spider is specified as an AISI 1050 warm-forged steel material. The required properties comprise a surface hardness on the trunnions in the range of R_C 58-63, with a hardened case depth of approximately 1.0-2.0 mm effective at R_C 50, and a core hardness of R_C 15-30. The microstructure is required to show martensite, preferably tempered martensite, in the case with fine grains of pearlite and ferrite in the core. The required hardness is necessary to provide the strength in the load bearing areas of the outer surface, and the necessary toughness and fatigue resistance in the core.

[0004] Spiders of various configurations have previously been hardened by carburizing to provide the necessary microstructural properties, such as those described above. The use of carburizing for case hardening has a number of well-known limitations. These include the fact that the process treats the entire surface of the component, the material and processing costs associated with the process, the processing time necessary to heat the parts to temperature and produce the required carburized case depth, as well as limitations related to process control, batch processing, capital expense and facility requirements for large furnaces, environmental issues, and control of the finished part quality. Also, the carburizing process has the potential to form undesirable microstructures, which include carbides, grain boundary oxidation, decarburization and retained austenite that can each affect the functionality of the finished part. Therefore, it is desirable to develop an improved method of heat treatment that addresses the

limitations mentioned above and that provides a method for surface or case hardening a part such as a spider.

[0005] Induction heat treatment is known to be an effective method of case hardening pearlitic/ferritic steels and avoiding many of the limitations mentioned above that are associated with carburizing. For example, induction hardening has been widely used for the case hardening of various types of steel gears. However, induction hardening has significant limitations in cases where the surface requiring heat treatment is irregular, such as gears having relatively larger teeth where the distance from the tip to the root of a tooth is such that the electromagnetic coupling, and hence induction heating, varies significantly from the tip to the root. While some solutions have been proposed to facilitate the use of induction hardening with articles having irregular surfaces, such as the use of a plurality of different coils and different induction frequencies to treat different portions of the surface, or the use of coil designs that are adapted to the contour of the irregularities in order to provide more uniform coupling, induction hardening has not been used for various types of irregularly shaped components, including spiders, perhaps because the use of the techniques described above are not applicable to provide a single pass induction heat treatment of the critical surfaces of a spider due to its irregular shape.

[0006] Therefore, it is desirable to develop an induction heat treatment method that can be utilized to provide induction hardening of irregularly shaped components, particularly those that comprise a hub and a plurality of trunnions extending outwardly therefrom, such as the various spiders utilized for tripod-type constant velocity joints.

SUMMARY OF THE INVENTION

[0007] The present invention provides a method of induction heat treatment, comprising the steps of: (1) selecting an article, such as spider, for heat treatment comprising a hub having a hub surface and a plurality of angularly spaced trunnions extending from a corresponding plurality of trunnion shoulders formed in the hub surface, each trunnion shoulder having a trunnion shoulder surface, and each trunnion having a trunnion axis and a trunnion surface; (2) selecting an induction coil, which is adapted to receive a trunnion for heat treatment and apply a magnetic field to the trunnion surface and trunnion shoulder surface; (3) placing a trunnion within the induction coil with its corresponding trunnion shoulder adjacent to the induction coil; (4) rotating the trunnion within the induction coil about the trunnion axis at a selected speed; (5) energizing the induction coil to apply the magnetic field and produce induction currents within the trunnion shoulder surface and trunnion surface of the article for a time sufficient to induce heating them to a heat treatment temperature (T_H) to at least a selected case depth; (6) withdrawing the trunnion from the induction coil at a selected rate; (7) cooling the trunnion surface and trunnion shoulder surface of the article to a temperature (T_C) to the selected case depth; and (8) repeating steps (3)-(7) for a selected number of the trunnions.

[0008] More particularly, the present invention also provides a method of induction heat treatment of a spider having a barrel-shaped outer surface, a plurality of cylindrical trunnion shoulders formed in the outer surface of the hub and a corresponding plurality of angularly spaced cylindrical trunnions extending from the shoulders, each trunnion shoulder having a trunnion shoulder surface, and each trunnion having a trunnion axis and a trunnion surface, comprising the steps of: (1) selecting an induction coil, which is adapted to receive a trunnion for heat treatment and apply a magnetic field to the trunnion surface and the trunnion shoulder

surface; (2) placing a trunnion within the induction coil with its corresponding trunnion shoulder adjacent to the induction coil; (3) rotating the trunnion within the induction coil about the trunnion axis at a selected speed; (4) energizing the induction coil to apply the magnetic field and produce induction currents within the trunnion shoulder surface and trunnion surface of the article for a time sufficient to induce heating them to a heat treatment temperature (T_H) to at least a selected case depth; (5) withdrawing the trunnion from the induction coil at a selected rate; (6) cooling the trunnion surface and trunnion shoulder surface of the article to a temperature (T_C) to the selected case depth; and (7) repeating steps (2)-(6) for a selected number of the trunnions.

[0009] The present invention also includes an article, such as: a steel spider comprising a hub, a plurality of angularly spaced trunnion shoulders extending from the hub, each having a trunnion shoulder surface, and a corresponding plurality of angularly-spaced trunnions extending from the plurality of trunnion shoulders, each trunnion having a trunnion axis and a trunnion surface, the trunnion surfaces and the trunnion shoulder surfaces comprising a hardened case, wherein the hardened case is formed by an induction heat treatment.

[0010] Certain difficulties associated with the inductive heat treatment of components having an irregular outer surface, such as the spider of tripod-type CV joints, have been overcome by the use of the method of heat treatment and induction coil described herein.

[0011] The present invention undertakes to improve the production of such components as compared to previous methods, such as carburizing, by enabling the use induction hardening, and thereby providing better control over the hardening process by hardening one component at a time, improving the metallurgical and mechanical and properties of the components, and allowing for a reduction in heat treatment cost.

[0012] The hardening operation will be simplified, and allow improved control, by the application of this invention because the components will be processed one at a time. The integration of the part location, heating, and quenching functions into a single, robust machine simplifies the heat treatment operation compared to previous methods, such as carburizing, by reducing the part handling requirements and reducing complex cycle parameters (e.g. adjusting the entire process for part-to-part variations in a batch of parts due to different temperature and environmental conditions that exist in a large heat treating furnace) to a small set of control parameters for each individual part (e.g. power, induction time, quench flow rates, etc.). Enabling the automatic control of process variables, such as the power level, total power delivered, quench temperature, quench flow rate, and cycle timing parameters, along with other process variables, will enable improved process control.

[0013] The mechanical properties of the components may also be improved by the selective application of heat in only the areas where high hardness is desired to give more precise control over the hardness and properties of the critical areas of the component while minimizing distortion from the hardening process.

[0014] Benefits from this invention include increased component strength (as compared to components processed by conventional methods such as carburizing), use of lower cost materials, shortened process times, reduced forging costs, reduced distortion, improved microstructures, improved tool life, deeper case depth capabilities, and the use of cellular process lines.

[0015] Further scope of applicability of the present invention will become apparent from the following detailed description, claims, and drawings. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the

invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The present invention will become more fully understood from the detailed description given below, the appended claims, and the accompanying drawings in which:

[0017] FIG. 1 is a flow diagram illustrating the method of the invention.

[0018] FIG. 2 is a top view of an article of the present invention in the form of a spider.

[0019] FIG. 3 is a front view of the spider of FIG. 2.

[0020] FIG. 4 is a top view of an induction coil.

[0021] FIG. 5 is a cross-sectional view of the induction coil of FIG. 4 along section 5-5.

[0022] FIG. 6 .is a bottom view of the induction coil of FIG. 4.

[0023] FIG. 7 A is a cross-sectional view of an induction coil and spider illustrating step 30 of the method of the invention.

[0024] FIG. 7 B is a cross-sectional view of an induction coil and spider illustrating step 40 of the method of the invention.

[0025] FIG. 7 C is a cross-sectional view of an induction coil and spider illustrating step 50 of the method of the invention.

[0026] FIG. 7 D is a cross-sectional view of an induction coil and spider illustrating step 60 of the method of the invention.

[0027] FIG. 7 E is a cross-sectional view of an induction coil and spider illustrating step 70 of the method of the invention.

[0028] FIG. 7 F is also a cross-sectional view of an induction coil and spider illustrating step 70 of the method of the invention.

[0029] FIG. 8 is a cross-sectional view of section 8-8 of FIG. 2.

[0030] FIG. 9 is a cross-sectional view of section 9-9 of FIG. 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0031] Referring to FIGS. 1-7, the present invention generally comprises a method 1 of induction heat treatment, comprising the steps of: (1) selecting 10 an article 100, such as spider 200, for heat treatment comprising hub 210 having hub surface 215 and a plurality of angularly spaced trunnions 220 extending from a corresponding plurality of trunnion shoulders 225 formed in the hub surface 215, each trunnion shoulder 225 having a trunnion shoulder surface 245, and each trunnion 220 having a trunnion axis 230 and a trunnion surface 235; (2) selecting 20 an induction coil 300, which is adapted to receive a trunnion 220 for heat treatment and apply a magnetic field to the trunnion surface 235 and trunnion shoulder surface 245; (3) placing 30 a trunnion 220 within the induction coil 300 with its corresponding trunnion shoulder 225 adjacent to the induction coil 300; (4) rotating 40 the trunnion 220 within the induction coil 300 about the trunnion axis 230 at a selected speed; (5) energizing 50 the induction coil 300 to apply the magnetic field and produce induction currents within the trunnion surface 235 and trunnion shoulder surface 245 of the article 100 for a time sufficient to induce heating them to a heat treatment temperature (T_H) to at least a selected case depth; (6) withdrawing 60 the trunnion from the induction coil at a selected rate; (7) cooling 70 the trunnion surface and trunnion shoulder surface of the article to a temperature (T_C) to the selected case 250 depth; and (8) repeating 80 steps (3)-(7) for a selected number of the trunnions.

[0032] With regard to the step of selecting 10 an article 100, this method of induction heat treatment is ideally suited for the induction hardening heat treatment of articles 100, such as

spider 200, comprising a hub 210 having a plurality of angularly-spaced trunnions 220 or shafts extending from the hub surface 215, as illustrated in FIGS. 2 and 3. Preferably, spider 200 is formed from an induction hardenable metal, such as a medium to high carbon steel having a microstructure comprising a mixture of pearlite and ferrite. Induction hardenable steels are referred to herein as pearlitic/ferritic steels. Preferably, hub 210 and trunnions 220 are formed from a single starting blank, such as by forging. Hub 210 may be of any suitable shape, but is preferably generally cylindrical. Hub surface 215 may be any shape that is suitable to receive the trunnions, but is preferably barrel-shaped or convex. It is also preferred that trunnion shoulders 225 be formed in hub surface 215 and extend outwardly from hub 210, and that trunnions 220 extend radially and outwardly from trunnion shoulders 225. Trunnions 220 may comprise any suitable shape, but preferably comprise a right circular cylinder as illustrated in Figs. 2 and 3.

[0033] While it is believed that the method of the present invention may be used for the induction heat treatment 1 of a number of articles 100 of the type described above, FIGS. 2, 3, 8 and 9 illustrate a particular embodiment of article 100, comprising a spider 200 of a tripod type constant velocity joint that Applicants have induction heat-treated using method 1. Spider 200 was generally cylindrical, having a hub 210 with a maximum diameter of about 100 mm and a thickness of about 40 mm and comprised AISI 1050 warm forged steel. Spider 200 comprised an outer surface 205, comprising hub surface 215, trunnion surfaces 235, and trunnion shoulder surfaces 245, and a core 240. Hub surface 215 was generally convex or barrel-shaped. Trunnion shoulders 225 were generally cylindrical, having a diameter of about 35 mm. In the embodiment illustrated in FIGS. 2 and 3, there were three trunnion shoulders 225, associated with three trunnions 220, however, the present invention is also applicable to

hubs 210 that contain more or less than three trunnions 220 or shafts. Trunnions 220 were about 40 mm long and 30 mm in diameter. Hub also comprised a bore 250, which was a splined bore, and is the means for attaching spider 200 to an axle shaft (not shown).

[0034] Referring to FIGS. 8 and 9, it is an object of the induction heat treatment to form an induction-hardened case over the entirety of trunnion surfaces 235 and trunnion shoulder surfaces 245. In the case of spider 200, these surfaces are primarily subjected to loads associated with the transmission of torque from a drive shaft to a driven shaft as a CV joint incorporating spider 200 is translated and angulated during operation of a vehicle. Therefore, these surfaces have carefully defined mechanical requirements for strength, toughness and fatigue resistance, and corresponding microstructural requirements for hardness, case depth, phase constituents and distribution and other characteristics, such as those described above.

[0035] Tripod joints are presently made by a number of manufacturers. This being the case, there are many variations in the particular features and details of tripod joints and their associated spiders 200, including variations of the size, including the thickness and diameter, the degree and type of curvature of hub surface 215, the shape and size of trunnions 220, the composition of the material and methods used to form spider 200, and other features. However, while some differences exist, most spiders comprise pearlitic/ferritic steels, and it is believed that the present invention is applicable to many of the spiders currently being manufactured for tripod CV joints.

[0036] Having selected 10 article 100, such as spider 200, the method of heat treatment 1 comprised the additional step of selecting 20 an induction coil 300. Referring to FIGS. 4-6, the induction coil 300 selected comprised a cylindrical coil 300 having a cylindrical portion 302, a termination portion 304, and a longitudinal axis 306. Cylindrical portion 302 of induction coil

300 also preferably comprises an integral quench ring 308 that is fabricated so as to form an integral portion of cylindrical portion 302. Due to the fact that quench ring 308 extends inwardly of the inner sidewall of cylindrical portion 302, it also acts as a flux concentrator, such that the magnetic field is strongest and most closely coupled to article 100 within the bore of quench ring 308. Referring again to FIGS. 4-6, induction coil 300 may comprise any suitable size, cross-sectional shape and composition, depending on the exact nature of article 100 that is to be used therewith. However, in the case of spider 200, induction coil 300 had an effective inner diameter of about 38 mm and comprised a hollow, rectangular, copper tube having an internal width of 12.5 mm and an internal height of 12.5 mm, and a sidewall thickness of 2-3 mm. While many conductive materials may be used for induction coil 300, it is preferably made from pure copper tubing, generally having a purity of at least 99%. Induction coil 300 must be adapted so as to receive article 200, while preferably maintaining as close a spacing as is practicable, so as to maximize the inductive coupling with article 100 when induction coil 300 is energized, and yet not interfere with the rotation or withdrawal of article 100, as discussed below. Induction coil 300 is preferably adapted so that longitudinal axis 306 of coil 300 may be easily aligned to be parallel to and coincident with trunnion axes 230.

[0037] Induction coil 300 is also adapted to apply a planar magnetic field to the trunnion surfaces 235 and trunnion shoulder surfaces 245 of trunnions 220. By planar, it is meant that the centerline of the magnetic field that results when induction coil 300 is energized, which roughly corresponds to the centerline of the tube, defines a plane. Referring to FIGS 4-6, the magnetic field that is produced when induction coil 300 is energized may be described as being

generally cylindrical, corresponding to the shape of cylindrical portion 302 of induction coil 300.

[0038] Referring to FIG. 7A, the next step of method 1 comprises placing 30 the trunnions 220 of article 100, such as spider 200, within the induction coil 300. Placing 30 comprises providing a rotatable means for placing, rotating and withdrawing article 100 and performing the subsequent steps of method 1. As discussed above and illustrated in FIG. 7A with regard to spider 200, spider 200 is preferably placed within induction coil 300 so that trunnion axis 230 is parallel to and coincident with longitudinal axis 306 of induction coil 300. Trunnion shoulder 225 is placed adjacent to induction coil 300, such that the magnetic field produced when induction coil 300 is energized is inductively coupled to both the trunnion surface 235 and the trunnion shoulder surface 245. Spider 200 may be placed into induction coil 300 by any number of suitable known means for holding and rotating spider 200, such as a rotatable and translatable jig or fixture. It is also preferable that means for holding and rotating spider 200 be selected so as to minimize any interference with the magnetic fields generated by induction coil 300.

[0039] Referring to FIG. 7B, the next step of method 1 comprises rotating 40 spider 200 within induction coil 300 at a selected speed. This speed may be any suitable speed and may comprise a variable speed during or within the subsequent steps of method 1. Rotation is used to compensate for the fact that induction coil 300 has a region where the return legs 312 and 314 of termination portion 304 and generally cylindrical portion 302 meet where the resultant magnetic field is non-uniform and generally reduced as compared to adjacent sections of induction coil 300. In the case of the application of method 1 to spider 200 described herein, the rotational speed was about 100-200 rpm, preferably about 150 rpm.

[0040] Referring to FIG. 7C, the next step of method 1 comprises energizing 50 the induction coil 300 to a selected energy level to apply the magnetic field and produce an induction current within trunnion surface 235 and trunnion shoulder surface 245. In the case of steel, such as AISI 1050 steel, to provide induction hardening, this energizing 50 must be performed for a time sufficient to induce heating of these surfaces to a heat treatment temperature (T_H) to at least a selected case 250 depth, such as the required or desired hardened case 250 depth. As illustrated in FIG. 7C, in the case of spider 200, and induction coil 300, the step of energizing 50 comprised applying 60% power from a commercially available 60kW power supply of a type used for induction heat treatment in a range of about 350-400 kHz and preferably about 400 kHz. In the case of spider and trunnions, this step of energizing 50 was sufficient to heat all of trunnion surface 235 and trunnion shoulder surface 245 to a temperature that was above the austenite transition temperature to selected case 250 depth of at least 1 mm. The austenite transition temperature for the AISI 1050 material is about 1700-2000 °F. The actual depth of the heat treatment ranged from about 1 – 2 mm. It will be readily understood that the inductive frequency and power can be altered depending on the size, shape, composition and other factors associated with trunnion 220, the specific design of inductor coil 300, as well as other factors.

[0041] Referring to FIGS. 7D-F, the next step of method 1 comprises withdrawing 60 the trunnion 220 from the induction coil 300 at a selected rate along its longitudinal axis 306 so as to scan trunnion 220 within induction coil 300 and gradually withdraw trunnion 220 from induction coil 300. In the case of spider 200, the withdrawal or scan rate of the trunnion was about 0.098 cm/sec. Further, it is preferred that the steps of energizing 50, withdrawing 60 and cooling 70 be coordinated to provide a dwell at the initial placement position, in order that that trunnion shoulder surface 245 be heated above the austenite transition temperature prior to

initiating the step of withdrawing 60 and cooling 70. For example, in the case of spider 200, the dwell was about three seconds, after which trunnion 220 was withdrawn 60 to the position shown in FIG. 7E, whereupon cooling 70 was initiated while trunnion 220 was withdrawn 60 to the position shown in FIG. 7F.

[0042] The next step of method 1 comprises cooling 70 trunnion surface 235 and trunnion shoulder surface 245 of article 100 to a temperature (T_C) to the selected case 250 depth. This temperature (T_C) can be any temperature that is lower than the heat treatment temperature (T_H), but typically will be selected to produce certain desired transformation products within case 250. In the case of spider 200, the desired transformation product in case was martensite, hence, T_C was selected to be below the martensite transformation temperature, which in the case of AISI 1050 was about 200°F. Cooling 70 comprised quenching trunnion in an aqueous quenchant comprising 3-5% of a commercially available polymer quenchant additive, Aqua Quench 251, for a time sufficient to cool trunnion surface 235 and trunnion shoulder surface 245 below T_C. Quenching was accomplished by pumping a large volume of the quenchant through inductor coil 300 and quench ring 308 onto the trunnion surface 235 and trunnion shoulder surface 245. Quenching 70 was accomplished using quench ring 308 having a plurality of spray holes 310 in the lower surface of quench ring that were directed radially inwardly and downwardly towards longitudinal axis 306 of induction coil 200 as shown in FIGS. 7D and 7E. The quench time corresponded with the scan of trunnion 220 within induction coil 300, and for spider 200 was about 5 seconds. The quenchant flow rate was about 10 gpm.

[0043] Referring to FIGS. 8 and 9, following the step of cooling 70, the surface hardness of trunnion surface 235 and trunnion shoulder surface 245 were in the range of R_C 58-63, with a

hardened case depth range of approximately 1-2 mm effective at R_C 50, and a core 240 hardness of R_C 15-30. The microstructure comprised martensite in trunnion surface 235 and trunnion shoulder surface 245 and case 250, and fine grains of pearlite and ferrite in core 240.

[0044] Applicants believe that it is also possible to use method 1 to also produce a tempered martensite structure in case 250 by controlling the step of cooling 70 so that trunnion surface 235 and trunnion shoulder surface 245 are cooled by quenching such that T_C is in a range that is below the martensite start temperature (about 610°F) but greater than the martensite finish temperature (about 200°F), and then permitting the part to cool under ambient conditions, such that the martensitic structure is tempered by the residual heat in article 100 by means of the reduced cooling rate. Quench composition and concentration, temperature, flow rates and time are adjusted to allow the use of residual heat to sufficiently temper (stress relieve) the part, thereby eliminating the need for secondary tempering processing. It is believed that this will reduce the residual stresses in case 250, as well as the hardness to a range of about R_C 58-63. Applicants believe that this can be accomplished by shielding previously heat-treated trunnions from subsequent quenching 70, such as by use of a quench shield 320 as shown in phantom in FIG. 5.

[0045] Following the step of cooling 70, method 1 comprises repeating steps 30 through 70 for a selected number of trunnions 220. In the case of spider 200, it is preferable to perform these steps on all three trunnions 220. However, is it possible to apply method 1 to some or all of trunnions 220. Further, it is will be appreciated that the heat treatment for each trunnion 220 need not be the same, if the design criteria for trunnions 220 are not the same. Further, the heat treatment can be varied along the length of each of trunnions 220 and trunnion surfaces 235 should the design criteria so require.

[0046] Following induction heat treatment 1, spider 200 may optionally be hard turned to produce the finished dimensions of article 100.

[0047] The foregoing discussion discloses and describes an exemplary embodiment of the present invention. One skilled in the art will readily recognize from such discussion, and from the accompanying drawings and claims that various changes, modifications and variations can be made therein without departing from the true spirit and fair scope of the invention as defined by the following claims.